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Color Vision in the Bovine

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COLOR VISION IN THE BOVINE

by

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ABSTRACT

Color Vision in the Bovine

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Eight heifers were trained using operant conditioning to press a plate to receive a feed reward. Different wavelengths of light were presented as correct and incorrect stimuli. Positive and negative responses to the stimuli were registered electronically. Daily sessions of 17 minutes were conducted in a chamber with external light being excluded.

The duration of the stimulus was fixed at 17 seconds after which stimuli were randomly presented. Only presses on the plate when the correct stimulus was presented were reinforced with feed. A 75% correct choice was the criterion used as acceptable discrimination.

Ratios of correct to incorrect responses were computed. A stability of response was judged to occur when the median of these ratios over 5 days did not differ by more than .05 from the median of the ratios from the previous 5 sessions. Three colors i.e. green (535nm), red (610nm), and blue (450nm) were compared pairwise during 8 trials. Trial 7 was a repeat trial of green vs red and trial 8 was a comparison of green vs green.

Heifers gave random response to green vs green. Red was distinguished from blue by five of the heifers: 1, 2, 3, 4, and 5 at

76%, 91%, 78%, 88%, and 81% correct choice respectively. Blue was distinguished from green by three of the heifers: 1, 2, and 5 at 89%, 88%, and 85% correct choice respectively. Green was distinguished from red by three of the heifers: 1, 5, and 7 at 90%, 84%, and 85% correct choice respectively. These last discriminations were made in the repeat trial of green vs red after heifers failed to do so in the first trial of green vs red. Color discrimination and discrimination learning have been demonstrated by these results.

(46 pages)

INTRODUCTION

Color discrimination is easily determined in man by means of verbal communication and specialized stimulus objects. It is much more difficult however, to determine color discrimination in animals. To perceive color is to have a meaningful internal response to a specific wavelength, and to discriminate is to distinguish two specific wavelengths as two separate entities. The current study was an attempt to measure color discrimination in the bovine.

Research with humans has shown that subjects exposed to monotonous surroundings with no definite color become bored, lose their sense of perception and have deteriorated intelligence (Vernon, 1966). Prolonged exposure to orange (color names will be used with the understanding that specific wavelengths can be identified) improves social behavior, enhances optimism and lessens traits of hostility and irritability. Red causes expression of the patient's feelings of aggression and excitation. Green causes withdrawal from the outer world and retreat to one's own quietness (Birren, 1950).

A question of interest to animal scientists is whether exposure to different colors bring about similar effects in animals. Specifically could the color of the cow's environment encourage docility and discourage aggression and nervousness and subsequently improve managability. Gupta and Mishra (1978) have proposed that aggression and excitation could decrease milk production in the bovine, and docility could possibly increase production (Gupta and Mishra, 1978).

Color perception as well as discrimination in the bovine has yet to be determined. To determine the cow's ability to perceive color would be a difficult task, but to demonstrate color discrimination would be relatively easy. Schaffer and Sikes (1971) reported that dairy calves rapidly adapt to a training situation and could well prove to be a valuable alternative to the rat as a subject in comparative psychology experimentation.

Discrimination learning in dairy calves has been demonstrated by Grambling et al., (1970). Although dairy calves are able to solve simple discrimination problems, they vary in the rate of learning. Grambling et al., (1970) found that younger animals may achieve a greater number of correct turns in a maze than older animals, but the older animals appeared to recover from an incorrect turn more rapidly. Statistical estimates revealed small to moderate heritability for learning ability.

The dairy heifer would be a likely candidate to demonstrate color discrimination using operant conditioning because of domestication, previously demonstrated discrimination learning and availablity. It is hoped that the results of the present study can be applied to improvement in milk production. Any alteration of the bovine's surroundings leading to improved production would be of value to agriculturalists. If visual wavelength discrimination can be demonstrated, then further tests can be conducted to determine the effects of different colored environments on milk production.

LITERATURE REVIEW

Physiology of Vision

The first molecular event in vision is the absorption of a photon by the visual pigment in the photo-receptors of the retina. There is species to species variation in the absorption spectra of visual pigments. This variation is due to the variation in the placement of charged amino acid residues in the chromophore binding site (Barry and Mathies, 1982). Differences in the structures of the chromophore from pigment to pigment reflect variations in the chromophore's protein environment, thus modifying the absorption spectra.

Photon absorption produces a primary photo-product, batho-rhodopsin, that contains a distorted trans-retinal chromophore. At liquid nitrogen temperature (-196 C), bathorhodopsin can be trapped in a photo-stationary steady-state mixture between rhodopsin and isorhodopsin. Interactions between opsin and the chromophore have a profound effect on the absorption spectrum of the pigment. According to Walls (1942), the rhodopsin absorption maxima is approximately 495nm in the bovine eye vs. 500nm for man. Due to lack of precision in collection techniques (Jacobs, 1981) interpreting these results is not feasible.

The outer segment of the rods and cones has a photo-chemical which is sensitive to light. In the rods, this photo-chemical is called rhodopsin. There are various pigments in the cones which are very similar to rhosopsin except for a difference in spectral sensitivity. Mitochondria in the rods and cones supply most of the energy for the photo-receptor chemicals to perform their function (Guyton, 1981).

Each human retina contains about 125 million rods and 5.5 million cones (Guyton, 1981). However, there are major differences between the peripheral retina and the central retina, for nearer the fovea, fewer and fewer rods and cones converge on each optic fiber, and the rods and cones each become more slender. These two effects progressively increase the acuity of vision toward the central region of the retina because the number of cells per optic fiber decrease. In the very central region, the fovea, there are no rods at all, and the number of optic fibers going to the brain equal the number of cones.

The surface of the bovine retina is covered with blood vessels. The number of cones and rods per unit of surface area is higher in the cow than in the horse however, the ratio of cones to rods is almost the same: two to three rods per cone in the fovea while towards the papilla, there are five to six rods per cone (Rochon-Duvigneaud, 1943, quoted in Dabrowska et al., 1981).

Schultze (1866) deduced that cones of the vertebrate retina subserve photopic and color vision and that the rods serve as the photoreceptors of scotopic vision. This theory has been well established since then. The pig retina is rich with rods and cones (Miller and Snyder, 1977). They found the pig retina to be tiered in 2 layers; the first tier consisting of cones whose ellipsoids occupy most of that part of the retina. The second tier consists of rods which comprise the majority of the photoreceptor cells. The rod cells expand to fill the retinal cross-sectional area as the cones taper. Klopfer and Butler (1980) reported that swine respond to different intensities of light as color (between 420 and 760nm) and that their points of maximum sensitivity are not much different than man.

Most agriculturalists share a common goal of maximizing production at the least expense. The recent surge of interest in animal behavior (Curtis and Houpt, 1983) brings inquiry into the response of the animal to its environment and subsequent production. If cows perceive environment as humans do, internal responses could vary according to type and color of environment (Vernon, 1966; Goldstein, 1942). Greens and blues which have a soothing effect on humans, might be used to paint the quarters of cows with lively temperaments or dominating tendencies; while for docile cows shades of red, yellow and orange should be used (Cena, 1964a).

Color Vision of Rodents and Small Animals

Evidence of the bovine's ability to discriminate colors is scanty, however the cat has been shown to have color vision. For example, Mello and Peterson (1964) report that certain elements in the cat's visual system i.e., frequency of discharge in optic tract fibers, response latencies and tri-phasic spikes are differentially sensitive to wavelength. However, others have failed to demonstrate color vision in the cat (Deross and Ganson, 1915; Gunter, 1952; Meyer et al., 1954). The guinea pig has not demonstrated color discrimination. Guinea pigs failed to press more often when the light was green than when red or blue in color discrimination trials. A press on a green light brought positive feed reward whereas presses on a red or blue received no reward (Miles et al., 1956).

Watson and Watson (1956) observed spectral sensitivity of rodents to blue light. Rats have been shown to have color vision (Birch and Jacobs, 1975; Cicerone, 1976). The rabbit retina has good sensitivity to short wavelengths and poor sensitivity to long wavelength i.e., red (625nm) (Hoeshi and Golovine, 1965). Pigeons can discriminate color, however, it is possible that yellow and red may appear to them as a single hue, a unitary set of wavelengths (Cumming et al., 1965). Pigeons were trained to match wavelength in a three-key paradigm. Test trials, were occasionally presented where probe wavelengths appeared on the center key and choices were made to the stimuli presented on the side keys. These color-naming trials showed transition points between hues at 540nm and 595nm (Wright and Cumming, 1974).

Four squirrels (Sciuris vulgaris L.) were tested in a jumping stand on their color vision in 11,895 food training experiments. Subjects had to jump towards the correct stimulus to receive positive rewards. The correct stimuli were green, red, yellow and blue papers with 35 different shades of grey paper used as alternative choices. Following these trials comparisons were made with each color paper i.e., green against blue, green against red, etc. All squirrels learned to differentiate the correct colors from 35 grey papers and from the alternative colors. The remembrance of their last training color influenced their choices (Meyer-Oehme, 1957).

Color Vision in Ungulates

The term "discrimination" is the difference between the behavior of an organism on one occasion and its behavior on another occasion. What is important is not so much the change in behavior itself but the relation of the change to certain environmental events. In the case of discrimination, important events are usually considered to be those which precede and occasion different behavior, or different rates of emission of the same behavior (Gilbert and Sutherland, 1969). A pigeon may be said to discriminate red from blue if it consistently pecks a panel at a low rate when the panel is blue and at a high rate when the panel is red (Gilbert and Sutherland, 1969).

Alexander and Stevens (1979) reported color vision in sheep for color in the longer wavelength range, i.e., red, orange and yellow. They dusted pigments or mixtures of talc and carbon black into the coats of newborn lambs. Each ewe was presented with her lamb and then placed 7m from several other lambs, one of which was the color of her own lamb. The ewes showed a significant preference for the color of her own lamb when this color was red, orange, yellow and white, but ewes whose lambs were blue, green, light grey, a darker grey or black performed poorly. Munkenbeck (1982) demonstrated color discrimination in sheep using different colored light as stimuli. Four subjects were tested using a modified Y maze, forcing correct or incorrect responses. Colored light cues brought a positive reward while the alternative choice of grey with corresponding density resulted in an extended waiting period. Six wavelengths were tested using 10 nm bandwidth filters in 30 nm steps from 490 nm - 640nm inclusive. Discrimination criterion (85% correct choice) was reached by all subjects at all six wavelengths. Sensitivity to the colors was shown to decrease at 640 nm. (They could no longer discriminate the wavelength from corresponding grey of like intensity.)

Buchnauer and Fritsch (1980) found the domestic goat (Capra hircus L) able to distinguish the colors yellow, orange, blue, violet, and green from grey nuances of like brightness in 3-fold simultaneous choice situations. Percentages of correct choice were 85% or higher with all comparisons except that of blue which was 65%. Blue appeared to be the most difficult color to discriminate, being low in saturation and brightness (Walls, 1942).

Color vision has been demonstrated in a pygmy goat, a red deer cow, and a Nilgai antelope (Bockhaus, 1959a). The pygmy goat had to respond to stimuli (3 wavelengths which were isolated using a lamp and filters) to recieve a feed reward. Red (648nm) was compared to green (542nm), blue (395nm), blue (430nm), yellow (574nm) and violet (332nm). The goat made 93%, 80%, 83%, 90% and 52% correct choice respectively. The goat was able to discriminate colors from greys of like brightness with all correct choice percentages being 80%. Comparing violet with yellow (574nm), blue (395nm) and blue (430nm), 90%, 83% and 97% correct choice was made respectively. Comparing yellow (574nm) with blue (430nm) and green (542nm) 97% and 55% correct choice was made respectively. In the comparison of green against blue a 95% correct choice was made.

The Nilgai antelope (using a criterion of 85%) was not able to distinguish blue and green from corresponding greys of equivalent luminosity. However, it did distinguish yellow, orange and red from corresopnding greys.

The red deer distinguished 6 color regions; a slightly reddish violet, red, orange, yellow green, green and blue from each other and from shades of grey of equal brightness. Cards again were used and an 85% criterion was established to warrant discrimination. Using operant methods, presses on one of the two platforms placed below the cards brought a positive feed reward.

The giraffe could distinguish red and white cards (90% correct choice) by the 13th day of training using operant conditioning methods. With pigment cards, the giraffe distinguished the colors red, orange, yellow, yellow green and violet from 34 different shades of grey. The correct card from one of four cards placed randomly in front of the animal had to be chosen. The discrimination criterion was set at 59%. All correct choice percentages were 70% or above, and the majority were 85% and above. The giraffe could distinguish green only in triple choice experiments and not in quadruple. Grzimek (1952) found similar differences in the horse. The giraffe was able to discern blue from 12 different shades of grey but it took a long time to do so (Bockhaus, 1959b) indicating difficulty in discriminating blue.

Again using pigment cards with four choices and in addition filtered lights with two choices, the giraffe distinguished blue, violet, red, yellow, and green. Discrimination was concluded to have occurred when correct choice percentages reached the specified criterion which varied according to the number of trials conducted (Bockhaus, 1959b).

Klopfer and Butler (1980) trained swine to receive positive rewards for correct choices of a specific wavelength. The study included trials at 465nm, 680nm and 575nm. These were compared against varying wavelengths. Points of maximum sensitivity to these wavelengths were found to be similar to those of man and wavelength difference thresholds were 20nm apart.

Color Vision in the Bovine

Dabrowska et al., (1981) found cows of the Lowland Black and White breed able to discriminate seven colors in Ostwald's (1931) scale: yellow no. 2, pink no. 5, red no. 7, violet no. 12, blue no. 15, green no. 21, and yellowish green no. 23 from 16 shades of grey in Hering's (1878) scale. Thines and Soffie (1977) found dairy cows able to discriminate six different colors; blue, purple, orange, yellow, red and green from grey cards of equivalent luminosity. Further tests demonstrated color discrimnation for all colors used except blue and purple.

Stratton (1923) hung strips of cloth high enough so that 40 cattle of different age, sex, and breed could easily walk under them. These cloths were white, red, green and black. He reported no strong excitement from the colors as a whole or from any one of them. There was interest, hesitation and caution toward all and any of the banners, as toward any strange things. None of the banners caused anything recognized as anger. Brightness and motion caused more reaction than did hue. A slightly greater interest and mistrust was shown toward white than toward any other color. Sex of the animals made no apparent difference in response to the different colored cloths.

Stratton (1923), in order to verify everyone's belief that the color red entices bulls to fight, circulated a questionaire to 64 people in California who were familiar with cattle. Results indicated no effect of the color red on the temperament of bulls.

Kittredge (1923) obtained negative results in experiments with a calf tested for its reaction to red and greys of different intensities. The calf had to choose between two doors, a red one (Bradley saturated red) and 3 Hering greys 7, 15 and 50. Warm milk in a bucket was placed behind the red door with the red door being alternated so the calf did not associate reinforcement with it's position. Daily trials of four comparisons were made. The calf demonstrated perfect discrimination of Bradley saturated red from light grey (Hering grey 7) with 5 perfect records in 5 consecutive days. When comparing the red with Hering grey

15, discrimination decreased and comparison of red with Hering grey 50 indicated random choice. The calf had difficulty discriminating the darker grey from Bradley saturated red.

Hebel and Sambraus (1976) quote color discrimination tables for various animals in which the failure of cattle to distinguish red is noted. Barry and Mathies (1982) reported that the peak absorption for the rhodopsin of the rods in the cow eye occurs at 505nm. This disagrees with Walls (1942) who reported the rhodopsin absorption maxima at 495nm in the cow eye. Jacobs (1981) indicates that precision is low in collecting rod absorption data and caution should be used in interpreting such data.

Discrimination Data Analysis

Baldwin (1978) demonstrated shape discrimination in goats and in sheep and calves (Baldwin, 1981). Subjects were trained to press one of two levers subsequently receiving a feed reward for a correct choice. Shapes used for visual discrimination were 1.75cm x 1.75 cm and were projected upon transparent response panels by means of "in line" display units. Shapes such as crosses, triangles and horizontal bars were used as stimuli. Each trial was terminated after 300 correct choices on an FR(6) (reinforcement for every 6 presses) ratio. Discrimination was concluded with 150 or less incorrect choices (2/3 or more correct choice).

Arave et al., (1983) in taste preference trials using operant methods, (Moore et al., 1975), judged overall stability of response to occur when the median of the ratios (left response to total response) over 5 days did not differ by more than 0.05 from the median of the ratios of the previous 5 sessions. Data from the last 5 sessions were used for statistical analysis using a chi-square for deviations from 0.5.

Dabrowska et al., (1981) used a 68% correct choice criterion for demonstrated color discrimination in the bovine. The discriminations were also verified statistically (by t test).

Blakeman and Friend (1981) used operant methods in a study to test visual discrimination at varying distances with 3 Spanish goats. The goats had to discriminate visually between a 3.4cm "X" and an "O", projected one at a time on a caramate projector. They were trained to press one of two panels when the "X" was projected and the other panel when the "O" was projected. Incorrect responses brought a 20 second delay in the trial. Daily trials of 20 minutes were run with a criterion for discrimination set at 75% correct choice. When criterion was reached, the distance away from the stimulus was sequentially increased 0.10, 0.25, 0.50, 0.75 and 1.0 m. All goats were able to reach criterion at all 3 distances, but the time it took for each goat to reach criterion varied from 8-18 trials.

Discrimination was verified according to Munkenbeck (1982) when a criterion of 85% correct choice was reached on 2 successive 20 min trials. Most criterion for discrimination in these trials were arbitrarily set between 59% and 90%.

MATERIALS AND METHODS

Subjects

Eight Holstein heifers weighing approximately 500 kg at the beginning of the study were used in color discrimination trials: 5736 (no.1), 5738 (no.2), 5742 (no.3), 5744 (no.4), 5746 (no.5), 5748 (no.6), 5750 (no.7), and 5752 (no.8). All were previously trained through operant methods to obtain a feed reward by pressing a plate (Cate et al., 1978). During training, heifers were reinforced with a standard dairy mix consisting of rolled barley, corn, beet pulp, wheat bran, malt sprouts, and cotton seed. As animals improved in performance, closer and closer approximations to the plate were required until plate pressing actually occurred.

Heifers were on a rich reinforcement schedule [fixed ratio (FR 1) feed reinforcement each press] during training (Moore et al., 1975). Following training, subjects were on a variable interval schedule [(VI 14) reinforced on the average every 14 seconds but varying from 4 to 28 seconds]. This kept the heifers responding consistently. Using this schedule, they were subjects in a feed preference trial for six months prior to the current study.

During the current study, heifers were maintained on alflafa hay, silage, and dairy mix with water available free choice. All heifers were pregnant and were housed in a semi-open pen near the operant chamber.

Apparatus

An operant chamber 1.8m X 3.7m X 2.7m was used during the study.

External light was excluded from the chamber. A pneumatic device developed at Utah State Univ. (Daley et al., 1968) for presenting monochromatic visual stimuli was installed at the end of the chamber opposite the entrance. This device could be used to present a 5.0cm X 5.0cm stimulus at eye level for subjects to view.

A feed device patterned after one developed at Ruakura Agricultural Research Centre, Hamilton, New Zealand, (Moore et al., 1975) was installed directly in front of and below the stimulus. A metal screen was installed between the feeder and the color stimulus to prevent damage to the stimulus apparatus. The feed device consisted of a plastic bucket encased in a metal cylinder, open at the top. The plastic bucket was filled with feed and made accessible to the cow by a ram operated by air pressure. Directly above and anterior to the bucket was a plate 10cm in diameter. Presses on the plate engaged the pneumatic ram making the feed accessible to the cow for 3 seconds before being lowered. The metal cylinder had a partial lid which allowed subjects access to the the bucket when raised but allowing no accessibility when lowered.

The feeder was anchored securely to the cement floor on four legs. Electrical counters, air compressor, timing devices, and relays were all located next to the chamber in a clean and dry location.

Wratten filters (Daley et al., 1968) intercepting the light source to isolate broad spectral bands were the stimulus. The filter assembly enclosed a 5.0cm X 5.0cm Bausch & Lomb narrow-band interference bracket. One of three filters was actuated to intercept the light and give a specific wavelength. Each filter frame was actuated independently with a positive piston drive. Collumated light passed through the filter and through an opening for subjects to view. The sliding action of each filter frame was accomplished on two 0.64cm in diameter, cold rolled steel guide rods, mounted in parallel and firmly fastened to the main baseplate. These pistons would slide the filters into the operating position. The piston was operated by air pressure (5.6 kg/sq. cm) and as it was released, compression springs returned the filters back to normal resting position.

Air was supplied to the chamber for each filter assembly by a hose connected at one end to the cylinder chamber with a special fitting and at the other end with a Schrader three-way solenoid valve.

Procedure

All eight trained subjects received daily (5 days per week) sessions of 17 minutes each in the chamber. All eight subjects completed eight different trials excepting heifer no. 2 who died (no known reason of death) and no. 4 who calved and therefore, stopped participating before the study was finished. Each trial compared two different wavelengths; one wavelength being the correct choice and the other arbitrarily designated as incorrect. Colors as stimuli would come on randomly for 17 seconds each. Between stimuli, there was a 5 second pause with no stimulus. This pause had to occur without any presses before the random stimuli would reappear. Electronic counters were used to register the number of correct and incorrect presses and the presses occurring when no stimulus was present. Forcing a 5 second pause with no presses before reappearance of the stimuli prevented the subjects from being reinforced by the stimulus on an incorrect press. It also avoided any anticipation responses to the ensuing stimulus.

All subjects received seven weeks training of 17 minute daily sessions in the chamber. They learned to associate white light with feed reward. Responses when the white light was off brought no reward and was considered an incorrect response.

Following three weeks of this training, the white light was covered with green celophane paper and contrasted with no stimulus as incorrect choice. The green light was on for 17 seconds vs 30 seconds of no stimulus. Following a week of this training, the 535 nm wratten filter was used as correct stimulus vs darkness as incorrect choice. The first trial was initiated after one week of this training.

Green (535nm) as correct choice was compared with red (610nm) as incorrect choice during the first trial. The proportion of correct to incorrect responses was computed. Stability of response was judged to occur when the median of these ratios over 5 days did not differ by more than .05 from the median of the ratios from the previous 5 sessions. When this condition was met 5 consecutive times, the trial with these two particular colors was considered complete (Arave et al., 1983).

The second trial compared red as correct vs green as incorrect; third trial red correct vs blue (450nm) incorrect, fourth trial blue correct vs red incorrect. Trials five and six were green correct vs blue incorrect and then blue as correct and green as incorrect respectively. A repeat trial of green vs red (trial 7) was made to determine whether learning had occurred over time and a final trial of green (531nm) correct choice vs green (538nm) incorrect choice was conducted. These two wavelengths were difficult if not impossible to discriminate through the human eye. This trial was used as a control to determine if subjects were discriminating position of filter or something other than different wavelengths.

A ratio of correct presses to total presses and order of entrance into the chamber was recorded each day. Dominance rank (DR) of each heifer was determined. Daily correct response (CR) and overall response (OR) by day was determined and recorded.

Chi-square tests for deviations from 0.5 were made on last 5 sessions for each trial. The number of significant deviations was noted and reported as an average for each heifer and each trial (DEV). Homogeneity of response (HOM) was measured via a chi-square test on the last 5 sessions of each trial. Number of non-significant trials was noted and listed by subject and by trial. Average number of days taken by each heifer to stabilize (DAYS) was noted as was average number of days taken to stabilize by trial. Simple correlation coefficients were determined from these different parameters.

RESULTS AND DISCUSSION

A criterion of seventy-five percent correct choice was arbitrarily set for discrimination in this study. Baldwin (1981) used a 67% criterion for shape discrimination with sheep and calves. Schaffer and Sikes (1971) used a 90% criterion for discrimination learning in calves but their calves had to approach one of two buckets in a Y shaped run. Wrong choices meant more expended energy than a wrong choice when pressing plates. The subjects in this study could have reached the 67% criterion level used by Baldwin (1981) by pressing the plate every time a color came up and then continuing to press upon receiving a feed reward. The 75% criterion was an attempt to rule out discriminations made via this behavior.

The mean percentages of correct choice for the last five sessions for each heifer on each trial are listed in Table 1. For example, subject 5 averaged 81.4% correct choice in discriminating red from blue. There were eight trials in this study, the seventh being a repeat of the first trial and the eighth a comparison of two very similar wavelengths, i.e. 531nm and 538nm. Means and standard errors for CR, OR, DEV and DAYS are shown in Table 2.

Heifer no. 1 showed discrimination above 75% in 4 of the 8 trials. All trials except the green vs red replication were nonsignificant ($P<.05$) with the chi-square test for homogeneity. She demonstrated discrimination above the 75% criterion when comparing red vs blue (76.2%), blue vs red (77.2%), blue vs green (89.2%) and the replication of green vs red (88.9%). Her inability to discriminate green from blue might be due to her not being given enough training time.

Stabilization in this trial took 12 days as compared to her previous times of 16, 17 and 15 days.

Heifer no. 2 showed highest number of correct choices throughout the study as indicated in table 2. She reached criterion in the same trials as heifer no. 1 with the addition of the G-B trial. She died during the green vs red replication series. Heifer no. 2 discriminated red from blue, blue from red and blue from green.

Table 1. Mean correct response (CR) for each heifer on each trial for the last 5 sessions.

TRIAL	HEIFER							
	1	2	3	4	5	6	7	8
G-R[b]	63.1	61.3	59.5	66.2	59.8	56.2	45.1	60.2
R-G	62.9	67.8	65.9	70.1	67.8	58.9	65.1	60.1
R-B	76.2[a]	91.1[a]	77.7[a]	87.8[a]	81.4[a]	66.3	67.9	71.8
B-R	77.2[a]	83.1[a]	70.7	65.8	64.3	60.3	67.5	65.9
B-G	89.2[a]	87.6[a]	65.9	71.4	85.0[a]	62.1	63.0	61.3
G-B	74.3	77.9[a]	61.4	70.6	72.7	59.0	61.2	51.6
G-R	88.9[a]	----	74.3	67.1	84.0[a]	73.4	85.4[a]	57.4
G-G	65.5	63.8	62.4	----	71.7	57.0	53.6	61.5

[a] Reached 75% discrimination criterion
[b] G = green (531nm) R = red (610nm) and B = blue (450nm)

Heifer no. 3 failed to reach discrimination criterion in any trial except red vs blue. She showed a significant deviation from 0.5 in 4 out of 5 trials (table 2). At the beginning of each stimulus interval, she would press the plate and if reinforcement did not occur she ceased to press the plate and waited for the next stimulus. If reinforcement occurred with the first press, she continued to respond until the stimulus went off. This explains the high number of significant deviations from 0.5 found in the last 5 sessions of each of her trials.

Three heifers showed very high (90% or above) discrimination at one point or another during the study. Heifer no.4 showed a high discriminatory ability with red vs blue (87%) and heifer no. 5 showed high discrimination when blue was compared to green (85%). Her discrimination during the replication series of green vs red was also high (82%). It is interesting to note that heifer no. 7 demonstrated discrimination in the replication series green vs red after failing to discriminate between the three specific wavelengths in the first six trials. Subjects no. 1 and 5 also demonstrated discrimination in the

Table 2. Means and standard errors of each heifer for correct response (CR), overall response (OR), significant deviations from 0.5 (DEV) and days to stabilize (DAYS).

HEIFER	CR		OR		DEV		DAYS	
	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
1	74.7^{ab}	3.5	83.0^{e}	16.9	4.5	.25	13.3	.89
2	76.1^{a}	3.9	103.0^{ab}	13.8	4.1	.35	15.9	.92
3	67.2^{c}	2.1	107.5^{ab}	15.0	4.0	.31	13.4	1.4
4	71.3^{b}	2.5	109.9^{a}	4.9	4.3	.16	12.1	.43
5	73.3^{ab}	3.1	100.7^{bc}	13.0	4.4	.30	12.6	.82
6	61.7^{d}	1.9	94.3^{cd}	9.4	2.5	.43	12.6	.96
7	63.6^{cd}	3.9	102.4^{ab}	12.6	3.9	.39	12.9	1.4
8	61.2^{d}	2.0	88.8^{de}	18.2	2.5	.31	13.5	1.4

^{abcde}Means in same column with different superscripts differ significantly ($P<.05$).

replication series of green vs red after failing to do so in the initial green vs red comparison. All other subjects, excluding no. 8, improved in correct response in the replication series of green vs red. This shows that given enough time or sufficient trials, learning does occur. Some subjects never did become trained and subsequently failed to demonstrate color discrimination (heifers no. 6 and 8).

In the chi-square test for significant deviations from 0.5 in last 5 sessions ($P<.05$), both heifers nos.6 & 8 showed only 2.50 significant deviations(table 2). The other heifers had 4 or more significant deviations in the last 5 sessions of each trial. Heifer no. 1 had the highest significant deviations from 0.5 (4.5).

Heifer no. 1 was most consistent of all subjects in response during the last 5 sessions of each trial. Seven of eight trials were nonsignificant ($P<.05$) in a chi-square test of homogeneity (table 3). There was a general lack of homogeneity among the last 5 sessions of each trial of the other 7 heifers, ranging from 2 to 6 homogeneous trials. This lack of homogeneity could be due to the sequence of correct and incorrect presentations of colors. Strings of 6 or 7 consecutive incorrect presentations may have frustrated heifers, caused nervousness and indecision in responding. After such strings, some heifers lost patience and started responding vigorously. Other heifers ceased to respond and retreated to the rear of the chamber.

Subjects learned the operant methods as young calves (approximately 6 months of age). Each calf received 17 minutes/day to learn the pressing behavior. The no. of days taken to learn plate pressing are recorded in table 3 as learning ability (LA).

Throughout the trial, subjects were allowed to enter the operant chamber at will. The order in which they entered was noted each day. For example, if heifer no. 5 was the last heifer to enter the chamber on Sept. 17, an 8 was recorded as her entrance order (EO) for that day. An overall mean of each heifer's entrance order was computed and listed in table 3.

Table 3. Dominance rank (DR), learning ability (LA), entrance order (EO) and homogeneity of response (HOM) of each heifer.

HEIFER	DR[a]	LA	EO[b]	HOM
1	8	17	7.7[c]	7
2	1	17	6.5[d]	3
3	6	10	3.6[e]	5
4	4	17	3.5[f]	5
5	3	20	1.8[g]	5
6	7	17	2.3[h]	3
7	2	10	4.5[i]	4
8	5	20	6.2[j]	5

[a] Larger numbers mean higher dominance.
[b] Mean daily entrance order.
[c-j] Means in same column with different superscripts differ significantly ($p<.05$).

Dominance rank (DR) among the eight subjects was determined using social encounter observations and are listed in table 3. Wins over losses were recorded for each subject and the subject with the highest percentage of wins was ranked the highest (Arave and Albright, 1976). An encounter was lost when one subject yielded space to the other, either by being forcefully ejected or moving to avoid contact. Subject no. 8 exhibited less aggressive behavior but was clearly dominant even though she engaged in fewer encounters. She was the heaviest heifer, had the second highest mean correct response, was lowest in overall response and was the last to enter the chamber every day. The least dominant heifer weighed the least, was 7th in order of entry, demonstrated the highest correct response (CR), and was 3rd to the lowest in overall response. Simple correlation coefficients among the different parameters recorded for each subject are listed in table 4.

Table 4. Correlation coefficients among heifer variables: correct response (CR), learning ability (LA), overall response (OR), entrance order (EO), significant deviations from 0.5 (DEV), homogeneity of response (HOM) and number of days to reach stabilization (DAYS).

Variables	CR	LA	OR	EO	DEV	HOM	DAYS
DR	.16	.06	-.77[a]	-.08	-.26	.77[a]	-.40
CR		.26	.10	.15	.83[a]	.47	.30
LA			-.47	.06	-.20	.15	.02
OR				-.36	.30	-.56	.22
EO					.10	.38	.59
DEV						.15	.06
HOM							-.30

[a] Significant at $P<.05$.

A significant negative correlation of DR and OR indicates a trend of decreased response with increased dominance. A significant correlation between HOM and DR indicated more dominant animals responding with more consistency. A high correlation between CR and significant deviations from 0.5 in last sessions is evident.

Table 5 includes simple correlation coefficients for CR, OR, DEV, HOM and DAYS as trial variables. The significant negative correlation (P<.05) between OR and DEV shows less response for trials which have higher numbers of significant deviations from 0.5. Correct response (CR) and DEV have a significant positive correlation which indicates an increase in significant deviations from 0.5 as CR increases.

Table 5. Correlation coefficients among trial variables: overall respone (OR), significant deviations from 0.5 (DEV), homogeneity of response (HOM), number of days taken to stabilize (DAYS) and correct response (CR).

Variables	OR	DEV	HOM	DAYS
CR	-.66	.96[a]	.59	-.45
OR		-.81[a]	-.58	-.01
DEV			.65	-.38
HOM				.21

[a] Significant at P<.05.

All subjects failed to discriminate in the first two trials of green vs red and red vs green. As stimuli were switched from red vs green to red vs blue, the percentage correct choice on all subjects immediately improved. Five of eight reached criterion on this comparison. Such improvement is evidence in support of discrimination learning in the bovine. Of the other 3 subjects who did not reach criterion, subject no. 3 was close (74%) and subjects 6 & 7 were well below criterion (64% and 66%) respectively.

When red and blue were interchanged so that blue was correct and red was incorrect, correct percentages immediately dropped well below 50% for all subjects followed by a gradual improvement over time.

However, only 2 of the 5 who reached criterion in the previous trial were able to reach criterion in this trial.

In the blue vs green trial, correct choice percentages were much higher than in the green vs blue trial which followed. In the blue vs green trial (blue being correct) heifers 1, 2, and 5 were well above criterion at 92%, 90%, and 90% respectively. When the comparison was reversed (green now correct), there were drops below criterion in these same heifers ie., 73%, 74% and 72% respectively. Heifers 3, 6, 7 and 8 had decreases in per cent correct choice when green was correct. There was some difficulty in discrimination when reversing two colors from correct to incorrect stimulus, in moving from trial to trial.

Jenkins (1961) reports intermittent reinforcement (no reward for response to the incorrect stimulus) increases resistance to extinction. Terrace (1966) refers to the incorrect stimulus as an "inhibitor" when learning occurs with errors. When colors were reversed in the present study, the previous incorrect color was acting jointly as an inhibitor and the correct stimulus. The time for extinction (decreased responding to the correct stimulus due to lack of reinforcement) to occur increased because training was done with errors in the present study. Increased precision could have been reached by allowing more time for training in the trials immediately following reversal of the stimuli i.e., reversing red correct and blue incorrect to blue correct and red incorrect.

The highest percent mean correct response for any trial was 77.5% (red vs blue trial). Following in order were green vs red repetition (75.8%) and blue vs green (73.2%). These three trials were significantly higher than the other trials (table 6).

Table 6. Means of each trial for correct response (CR), overall response (OR), deviations from 0.5 (DEV), days to reach stabilization (DAYS) and homogeneity of response (HOM).

TRIAL	CR	OR	DEV	DAYS	HOM
G-R[e]	59.5[d]	104.7[ab]	3.1	16.0	5
R-G	64.8[c]	107.0[a]	3.3	13.3	4
R-B	77.5[a]	88.6[d]	4.6	12.1	5
B-R	69.4[b]	96.6[bc]	4.0	12.6	6
B-G	73.2[a]	97.2[bc]	4.1	14.9	6
G-B	66.1[bc]	100.4[abc]	3.6	12.5	4
G-R	75.8[a]	93.1[dc]	4.1	12.0	5
G-G	62.2[cd]	99.7[abc]	3.1	12.4	3

[abcd]Means in the same row with different superscripts differ significantly ($P<.05$).
[e]G = green (531nm), R = red (610nm), and B = blue (450nm).

Criterion was not reached by any of the subjects in the final control trial of green correct vs green incorrect. This trial was significantly lower in percent correct response than the correct response registered in the red vs blue trial, blue vs red trial, blue vs green trial and green vs red replication trial (table 6). Lack of significance when comparing the control trial (green vs green) with the initial green vs red trial and the red vs green trial indicates discrimination learning had not yet occurred. The lack of significance between correct response in the control trial and the green vs blue trial indicates difficulty subjects had discriminating green from blue when green was the correct choice.

Lack of discrimination when comparing two very similar wavelengths (531nm and 538nm) indicates the subjects were discriminating color or wavelength in the previous trials. Criterion for discrimination was reached in the previous 5 trials. The fact that these animals could discriminate the wavelengths 610nm, 531nm, and 450nm but could not discriminate 531nm and 538nm strongly suggest color vision in the bovine.

Figures 1, 2 and 3 show comparisons of percent correct choice during the last 5 sessions of stable responding for each heifer in trials with the same color as correct response. For example, figure 1 shows all comparisons made with green as the correct color stimulus. Standard errors and 75% criterion are indicated. Discrimination learning is demonstrated in figures 4 and 5 by showing graphs of daily response of heifers no. 1 and 2. On day 1 of a new trial, correct choice decreased drastically and slowly increased over time until criterion was reached. This is strong evidence of color vision in bovine because of the dramatic decline in percent correct choice immediately following reversal of the stimuli. Heifers no. 1 and 2 were used as examples because of their demonstrated discrimination ability.

The final green vs green comparison was conducted under cold weather conditions, which cause various equipment problems. There was a slight decrease in the response of the pistons when activating the filters to intercept the light source. Occasional malfunctions of the impulse counters caused delays in the acquisition of data. The apparatus functioned properly through the trial except for the aforementioned problem.

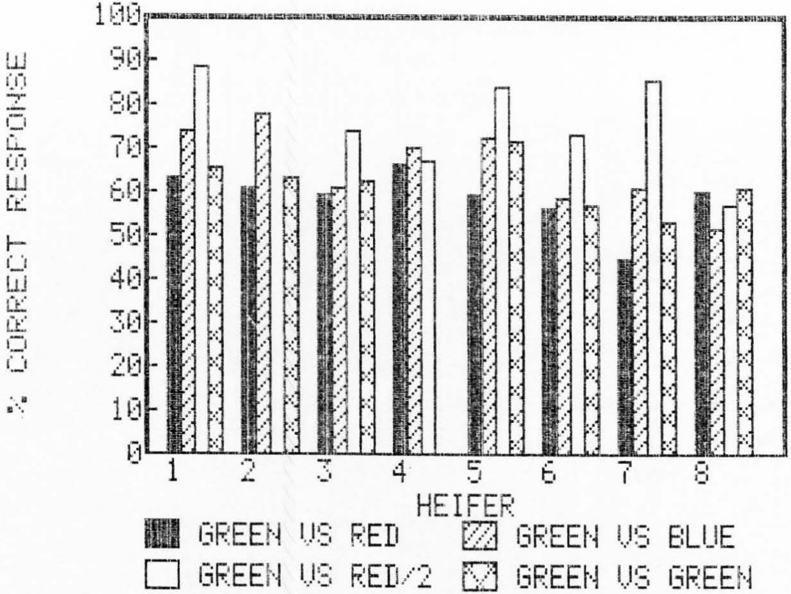

Figure 1. Correct response (CR) of all heifers in trials with green (531nm) as correct choice.

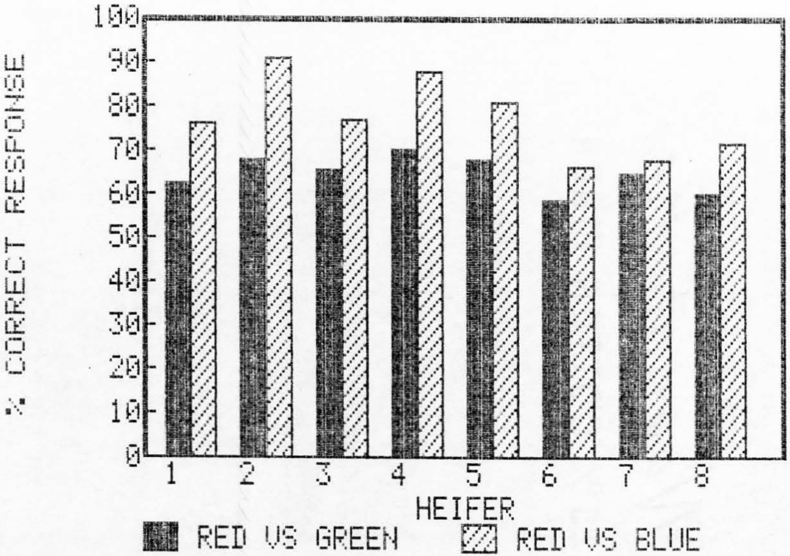

Figure 2. Correct response (CR) of all heifers in trials with red (610nm) as correct choice.

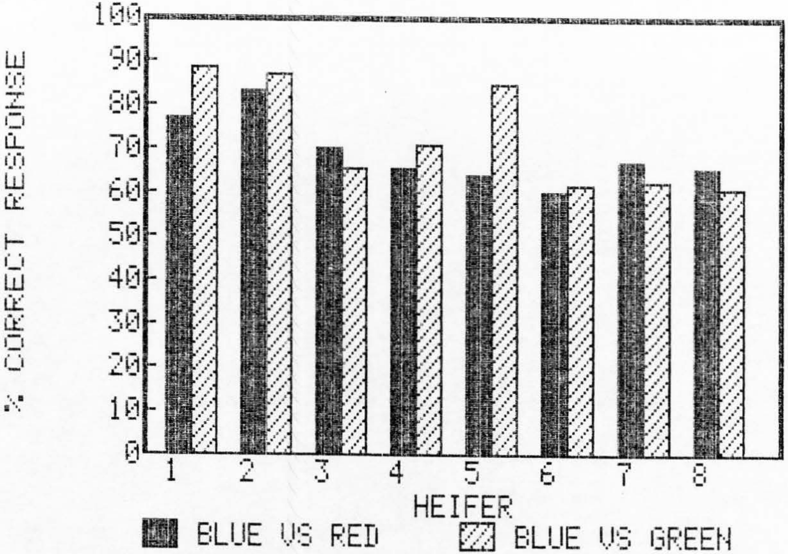

Figure 3. Correct response (CR) of all heifers in trials with blue (450nm) as correct choice.

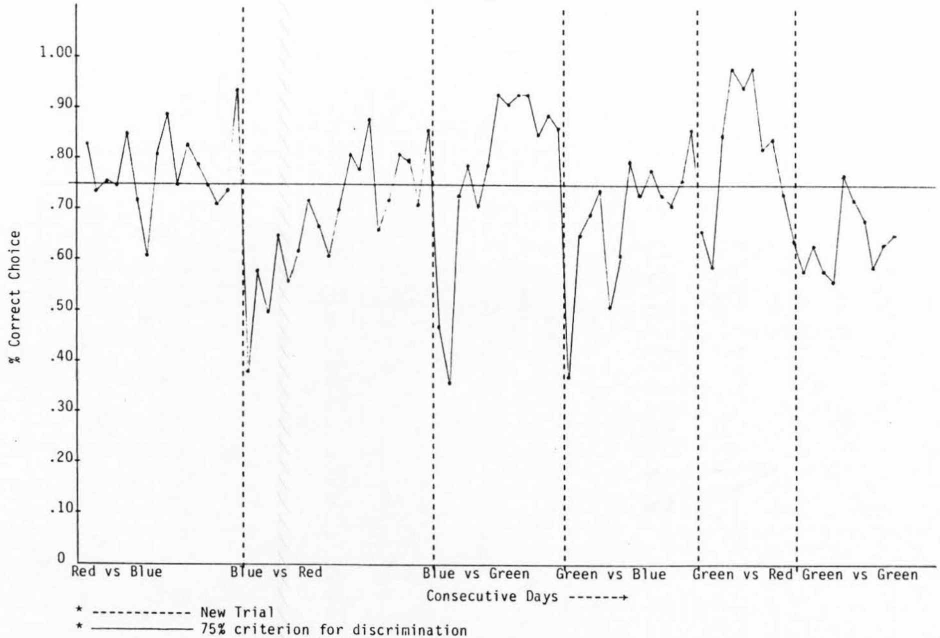

Figure 4. Daily correct response (CR) of heifer no. 1 through the last 6 trials.

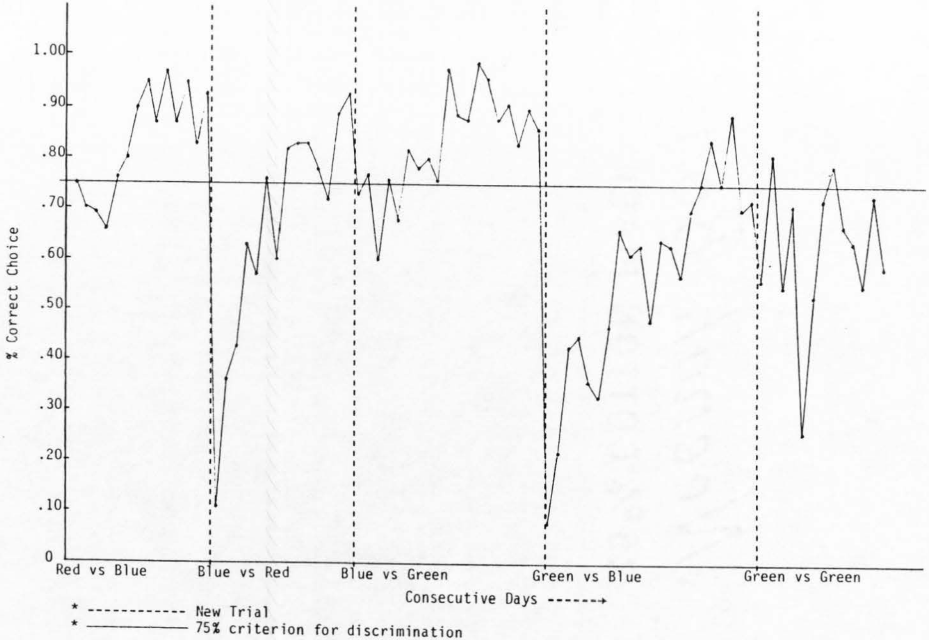

Figure 5. Daily correct response (CR) of heifer no. 2 through the last 5 trials.

The subjects were fed for normal growth, with an 8 hour fast period prior to their daily session. This was necessary to maintain a high level of response. Beginning and monthly weights are recorded in Table 7.

Table 7. Beginning and monthly body weights (Kg) for each heifer.

	HEIFERS							
MONTH	1	2	3	4	5	6	7	8
APRIL	527	414	529	527	523	514	486	498
MAY	541	418	532	539	527	518	505	511
JUNE	505	427	511	504	502	490	484	491
JULY	500	423	493	468	507	484	480	477
AUG	559	443	555	568	536	533	525	530
SEPT	600	464	591	618	593	580	545	566
OCT	643	482	609	---	636	600	568	609
NOV	650	491	636	---	645	623	591	623
DEC	691	---	---	---	686	659	609	673

CONCLUSIONS

Wavelength discrimination was demonstrated by five of the subjects completing this study. Three failed to discriminate for unknown reasons. The five who demonstrated discrimination in at least one of the eight trials did so by reaching a 75% correct choice criterion after the 5 day stabilization occurred. Three of the eight heifers reached a 90% correct choice level or higher.

In consecutive trials with the same two colors reversed, heifers had more difficulty making correct choices in the second trial. This was due to the incorrect stimulus acting as an inhibitor in the second trial. Amount of time for extinction to occur was increased because of intermittent reinforcement.

Discrimination was made between red and green, red and blue and blue and green. The expected difficulty in discriminating blue from green (Dabrowska et al., 1981) was apparent when comparing green as correct choice vs blue as incorrect choice. However, there seemed to be little difficulty in discriminating blue as correct choice vs green as incorrect choice. Subjects did not discriminate wavelengths which were very similar to one another i.e. 531nm and 538nm.

The discrimination of wavelengths 450nm, 531nm and 610nm is strong evidence for color vision in the bovine. No discrimination of the similar wavelengths 531nm and 538nm gives strong evidence that the subjects were discriminating the wavelengths (450nm, 531nm and 610nm) and not cueing in on some other unknown variable. A significant negative correlation with dominance rank and number of responses indicates fewer responses from dominant animals. Heifer no. 1 made the fewest responses and was the most dominant animal. She also had the least number of social encounters. There was no significant correlation between dominance rank and order of entry.

The significant correlation between dominance rank and homogeneity of sessions shows the dominant animals are more consistent in their performance. Discrimination ability is highly correlated with number of deviations from 0.5 in the last five sessions. Number of responses is correlated negatively with number of deviations from 0.5 in the last five sessions. Those animals more responses showed fewer deviations from 0.5 in the last 5 sessions.

The bovine's ability to discriminate different colors was apparent in this study. This helps to dispel beliefs that the bovine is color-blind. The dairy heifers functioned well as subjects in the operant learning environment used for this study. They responded well by pressing plates with their muzzles to indicate discriminations of their environment.

Further research could lead into monitoring heart rate after prolonged exposure to different colored environments. A milk production study of cows in different colored environments would also be of interest. According to a recent article (Costigan, 1984) pink surroundings tend to calm down individual humans who display aggression. What effect could similar changes in a cow's environment have?

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